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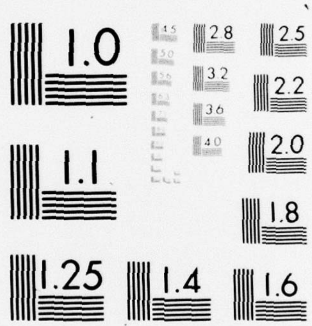

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COSMIC RAY VARIATIONAL COEFFICIENTS - THE EFFECT OF ALTITUDE VARIATIONS AND SECULAR VARIATIONS

O. H. Binder
Institut für Reine und Angewandte Kernphysik
University of Kiel
Kiel, Federal Republic of Germany

M. A. Shea and D. F. Smart
Air Force Geophysics Laboratory
Hanscom AFB, Bedford, Massachusetts 01731, USA

The extended sets of variational coefficients have been examined to ascertain the effects of altitude and also for possible differences arising from secular changes in the earth's magnetic field. An examination of the variational coefficients calculated for two closely positioned cosmic ray stations in Europe indicates that the altitude effects are small. A comparison of the variational coefficients calculated for three epochs of the geomagnetic field for Western Hemispheric locations where the geomagnetic field has its most rapid secular change indicates that the secular variation in the vertical cutoff rigidity (and associated changes in the asymptotic direction calculations) are such that the variational coefficients calculated using either a 1955 or a 1975 model of the geomagnetic field are adequate for most cosmic ray analyses.

1. INTRODUCTION

Several sets of variational coefficients for studies of diurnal variations and for transient cosmic ray phenomena have been published (McCracken et al., 1962; McCracken et al., 1965; Shea et al., 1968; Gold et al., 1974; Binder et al., 1976). The determination of these variational coefficients utilize asymptotic directions of approach derived from the calculation of cosmic ray trajectories through a mathematical model of the geomagnetic field. However, the geomagnetic field has a secular variation that can result in corresponding changes in these cosmic ray trajectories which will be most pronounced in areas where the secular changes are most significant. In this paper we have investigated the differences between the use of variational coefficients calculated using models of the geomagnetic field appropriate for 1955 and those calculated with geomagnetic field models appropriate for 1975 in order to ascertain the validity of utilizing the older tables for the analyses of recently acquired cosmic radiation data. In

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addition we have investigated whether significant differences occur in the variational coefficients calculated for a mountain and a sea level station closely positioned to each other.

2. METHOD

The same basic method was utilized to investigate both of these effects. First, asymptotic directions were calculated for the stations under consideration using the trajectory-tracing technique (McCracken et al., 1962) with an appropriate geomagnetic field model. Once the asymptotic directions were calculated, variational coefficients were determined for each of the stations, using the method described by Gold et al. (1974) and also followed by Binder et al. (1976). Cosmic radiation modulation spectral exponents ranging from -0.2 through +1.6 were considered together with various upper limiting rigidities from a minimum of 29 GV to a maximum of 500 GV. Next the first and second harmonic of the daily variation were computed and the changes in these values were evaluated for each effect being considered. Finally, the responses to hypothetical "square wave" anisotropies were calculated. These square waves were assumed to be independent of latitude having longitude widths of 10^{o}, 30^{o} and 60^{o} together with upper limiting rigidities from 500 GV down to 29 GV. The responses were then compared for the two effects under consideration.

3. SECULAR EFFECTS

Secular changes in the geomagnetic field result in significant decreases in the vertical cutoff rigidity for cosmic ray stations in the region of Latin America (Shea, 1971). Since the phase of the daily variation, as calculated by the variational coefficients, depends on both the vertical cutoff rigidity and the asymptotic cone of acceptance, we have investigated whether the secular changes in the geomagnetic field are significant in the calculation of the variational coefficients or in the application of these coefficients to the analysis of anisotropies in the cosmic radiation flux.

We have calculated asymptotic directions for four Latin American locations for three epochs of the geomagnetic field as follows: Buenos Aires (1965, 1975); Huancayo (1965, 1975); Mexico City (1955, 1965, 1975); and Ushuaia (1965, 1975). All calculations were made utilizing the trajectory-tracing technique with the following representations of the internal geomagnetic field: 1955 - Finch and Leaton sixth degree coefficients (Finch and Leaton, 1957); 1965 - International Geomagnetic Reference Field (IGRF) eighth degree coefficients (IAGA Commission 2, Working Group 4, 1969); and 1975 - International Geomagnetic Reference Field eighth degree coefficients (IAGA Division 1 Study Group, 1976).

TABLE 1

Vertical Cutoff Rigidities for Three Epochs

Station	Vertical Cutoff Rigidities (GV)		
	1955	1965	1975
Buenos Aires		10.22	9.88
Huancayo		13.24	13.04
Mexico City	9.53	9.12	8.88
Ushuaia		5.51	5.29

A comparison of the maximum differences in phase of the first and second harmonic of the daily variation for each of these stations between 1965 and 1975 (1955, 1965 and 1975 for Mexico City) show differences less than one hour in the phase of the first and second harmonic of the daily variation in the 10-year intervals considered. In most cases the differences are of the order of 10 minutes, far too small to be easily detected by present operational techniques.

An inspection of the results of responses to hypothetical "square wave" functions shows that the differences in maximum phase between two successive 10-year intervals were typically less than 15 degrees in longitude except for the extremely narrow and unrealistic anisotropy of 10 degrees in width. Figure 1 illustrates one of the major differences, a phase shift of 30° calculated for Huancayo for a square wave anisotropy 30° in width, and having a maximum upper limiting rigidity of 29 GV. Figure 2 illustrates a more typical case showing the differences calculated for Buenos Aires using a 60° wide square wave and 500 GV upper limiting rigidity.

Inspection of these results shows that whereas the asymptotic longitude of the maximum response may change somewhat depending on the geomagnetic field used in the original calculations, the changes in amplitude and general shape of the curves are so slight that they would be exceedingly difficult to observe experimentally. The slight differences that do exist are because of the wide spread of asymptotic directions near the cutoff value as suggested by Gall (1971).

4. ALTITUDE EFFECT

To investigate the altitude effect, asymptotic directions were calculated for neutron monitors at Bagnères de Bigorre (geographic latitude 43.08°, longitude 0.15°E, altitude 550 meters) and Pic du Midi (geographic latitude 42.93°N, longitude 0.25°E, altitude 2860 meters). The IGRF coefficients for Epoch 1975 (IAGA Division 1 Study Group, 1976) were used for these calculations. In comparing the first and second harmonic of the daily variation between these two stations, differences of less than 15 minutes were found for each harmonic. For the responses of these two stations to hypothetical square wave anisotropies, the differences in phase between the two locations are all less than 10° in longitude with the exception of the unrealistic case of a very narrow anisotropy of 10° in width. These differences are too small to affect the results of an investigation on spatial anisotropies.

The responses of these two neutron monitors to a square wave 60° in width and having upper limiting rigidities of 500 GV are shown in Figure 3. As illustrated, the location of maximum response is shifted by only 5° in longitude. For an upper limiting rigidity of 29 GV, the location of maximum response does not change. In addition, the general shape of the curves are very similar for the two locations, as can be seen from the illustration.

5. CONCLUSION

From these results we conclude the following:

(1) The altitude effect on the variational coefficients is very small for realistic anisotropies. Thus any differences in the application of these

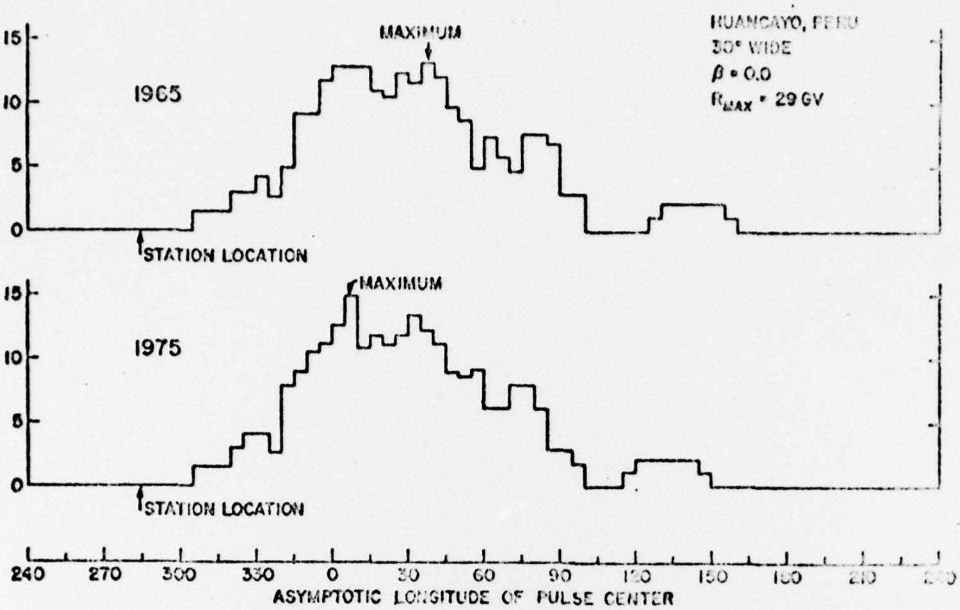

Figure 1. The response of a neutron monitor at Huancayo, Peru to a 30° wide square pulse cosmic ray anisotropy (lune of a celestial sphere) that extends to 29 GV and has a spectrum that is independent of rigidity for Epochs 1965 and 1975. The longitude of Huancayo is indicated by an arrow labeled "station location".

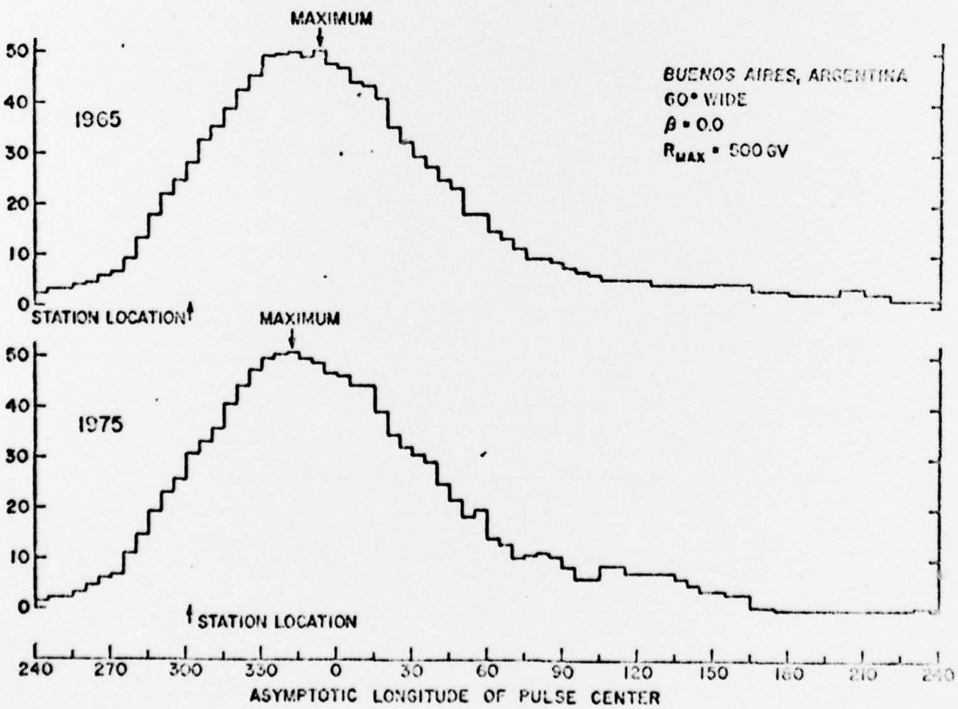

Figure 2. The response of a neutron monitor at Buenos Aires, Argentina to a 60° wide square pulse cosmic ray anisotropy (lune of a celestial sphere) that extends to 500 GV and has a spectrum that is independent of rigidity for Epochs 1965 and 1975. The longitude of Buenos Aires is indicated by an arrow labeled "station location".

variational coefficients to investigate cosmic ray phenomena cannot be ascribed to an altitude effect.

(2) The presently available tables of variational coefficients are adequate for the analysis of cosmic ray intensity variations from 1955 to the present time, and that the geomagnetic field utilized in the calculations of these tables is not a limiting factor in their use.

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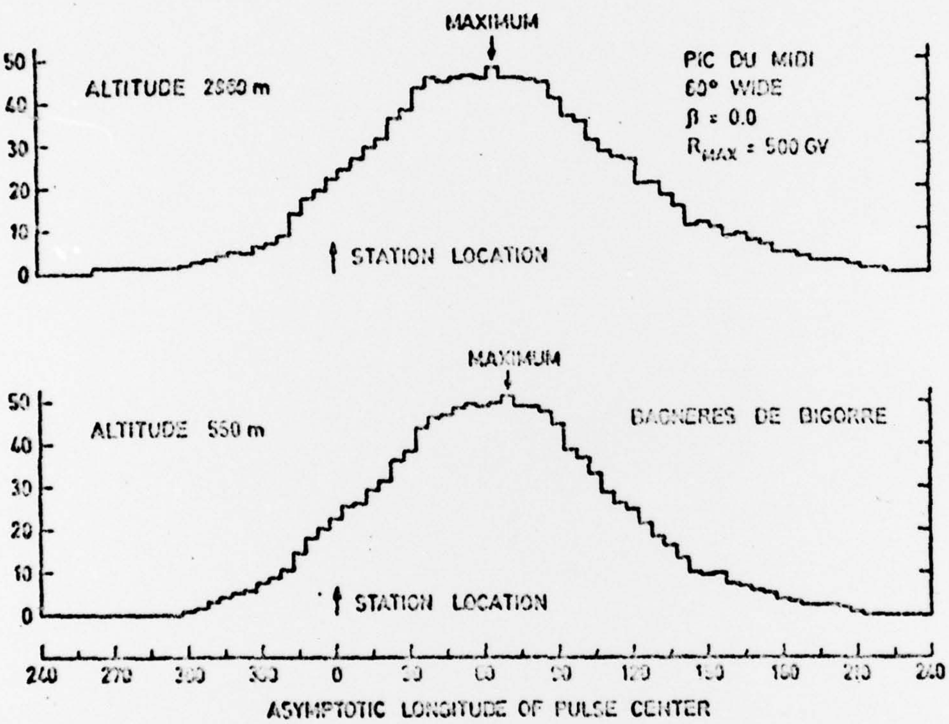

Figure 3. The response of neutron monitors at Pic du Midi and Bagnères de Bigorre to a 60° wide square pulse cosmic ray anisotropy (lune of a celestial sphere) that extends to 500 GV and has a spectrum that is independent of rigidity. The longitude of the stations are indicated by arrows labeled "station location".

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*Institut für Reine und Angewandte Kernphysik, University of Kiel, Kiel, FRG

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